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Study on EMI Analysis and Inhibitory Techniques for Switching Converter Devices

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Abstract—Due to the high power conversion efficiency, high efficiency and energy saving, wide voltage regulation range and light weight, switching converters are widely used in many fields such as industry, military, and medicine. However, strong electromagnetic interference can affect the normal operation of switching power supply and also has a negative impact on the external environment. Based on this phenomenon, we focus on the electromagnetic compatibility of switching power supply, and a high-frequency model for PSFB circuit is proposed. At last, a set of verification tests are conducted to verify the validity of the proposed model in this paper.

1. INTRODUCTION

Switching power supply uses an energy storage inductor and a capacitor to form an L and C filter circuit to filter differential mode and common mode interference signals. Due to the distributed capacitance of the inductor coil [1], the self-resonant frequency of the inductor coil is reduced, so that a large amount of high-frequency disturbance signal passes through the inductor coil and propagates outward along the AC power line or the DC output line. At the same time, as the frequency of the interference signal rises [2], the effect of the lead inductance causes the capacitance and filtering effect to decrease continuously, and even the capacitor parameters change, which is also a cause of electromagnetic interference [2].

Electromagnetic compatibility (EMC) refers to the coexistence state in which electronic devices can perform functions in a common electromagnetic environment. In addition to its own anti-interference ability, it is required to limit the electromagnetic radiation generated in the working state to a certain level [3]. Electromagnetic interference (EMI) can cause degradation in the performance of equipment, transmission channels, or systems. The path of the electronic system interfered with is through the power supply, through signal lines or control cables, field penetration, direct access through the antenna, coupling through the cable, conducted interference from other devices, internal field coupling of electronic systems, radiation interference from other devices and electronics. The device is externally coupled to an internal field, a broadband transmitter antenna system, and an external environmental field [4]. As an important electronic equipment, switching power supply should fully consider and meet the anti-interference requirements in order to avoid detours, save time, and avoid remedial measures against interference after the design is completed [4], which is the main motivation for initiating this paper.

The structure of this paper is organized as follows. Section 2 discusses theoretical analysis of time domain measurements and noise separation. Section 3 builds high frequency models based on phase-shifted full-bridge converter (PSFB). In Section 4, the relevant experimental verification is completed. Section 5 summarizes the work.

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2. THEORETICAL ANALYSIS

The modeling and prediction methods of electromagnetic interference can be divided into two categories: time domain modeling and frequency domain modeling [5]. Compared with the time domain EMI prediction method [6], frequency domain prediction is simpler, and it is widely used in EMI prediction of power electronic devices due to its rapidity [7, 8].

Conductive electromagnetic interference measurement system according to international standards adopts Line Impedance Stabilization Network (LISN). The power line contains both mixed mode and differential mode superimposed interference signals, but different filter performances and topologies are determined due to different modal signals. The selection of structure and parameters, so the measurement based on the LISN does not help the actual power line filter design and interference suppression. Since LISN measures the mixed noise signals of the common mode (CM) and differential mode (DM) signals, it is impossible to directly detect the specific CM and DM noise signals [2]. Visible electromagnetic interference common mode noise and differential mode noise separation techniques are designed to provide accurate separation of common mode noise signals and differential mode noise signals. The principle of independent component noise measurement technology is based on the addition and subtraction of noise voltages on the live and neutral lines in various circuit configurations and forms.

The input signal of the noise separator circuit is the noise voltage from the live line and the neutral line in the LISN, and the output signal of the circuit is the common mode (CM) or differential mode (DM) noise component [9, 10]. The differential mode output is connected to the spectrum analyzer, and the common mode output terminal is connected with 50 Ω matching impedance [11]. Conversely, if common mode noise is measured, the common mode output terminal is connected to the spectrum analyzer, and the differential mode output terminal is connected with 50 Ω matching impedance [12].

3. PSFB MODELING

The classic high frequency active topology of PSFB circuit topology is shown in Figure 1. Figure 2 shows the impedance characteristic curve of the 470 μF capacitor high frequency model. In the frequency range of 100 MHz, the measured results match the calculated results very well.

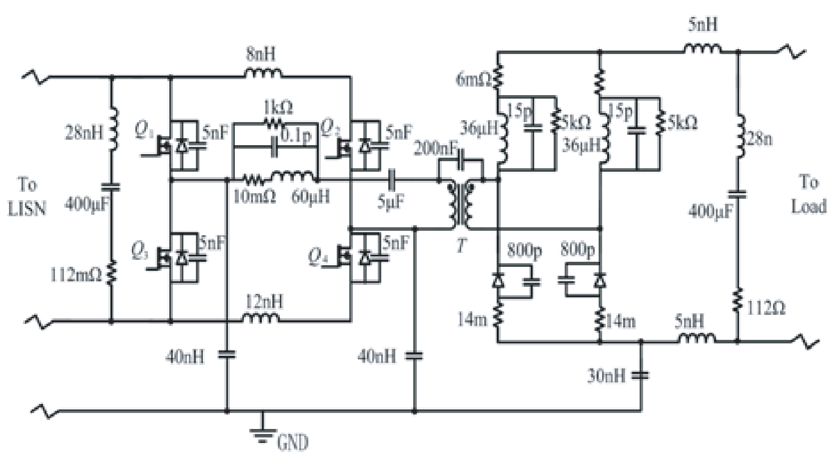


Figure 1. The high frequency active topology of PSFB.

3.1. Load Characteristics Modeling

The load model is modeled by a 16 Ω/200 W resistor, where Figure 3 is the ideal 4-element equivalent model, and Figure 5 is the impedance characteristic curve. In Figure 4, there is plurality of resonance frequency points due to the complicated load structure. The measured impedance of multiple resonant frequency points is converted into a high-order equivalent model by vector technique.

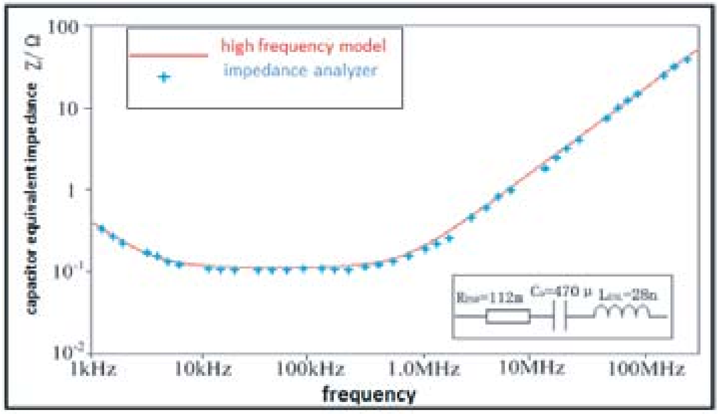


Figure 2. Capacitance equivalent impedance characteristic curve.

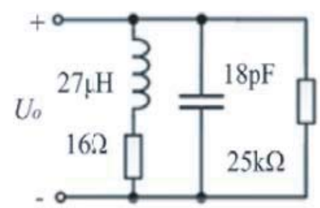


Figure 3. 4-element load model.

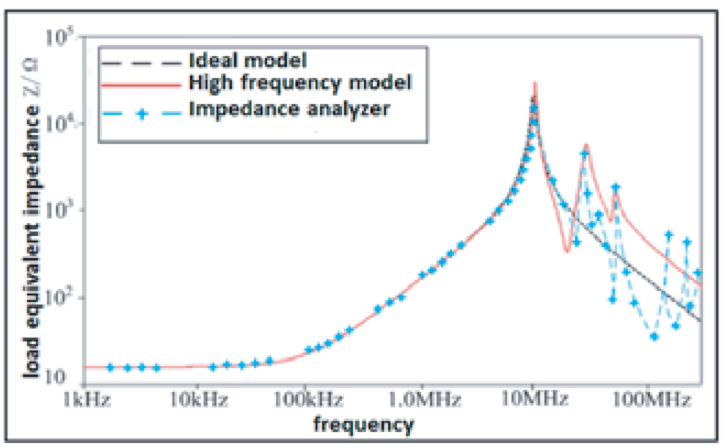


Figure 4. Load equivalent impedance characteristic curve.

3.2. Thermal Characteristics Modeling

The heat sink-to-ground capacitance has an important influence on the generation and propagation of CM interference [13], which can be estimated by the parallel plate capacitance equation [14].

$$C_H = \frac{\varepsilon_0 \varepsilon_r A}{s} \tag{1}$$

where ε_r is the dielectric constant of the heat sink insulation, A the surface area of the MOSFET pull ring, and s the insulation thickness.

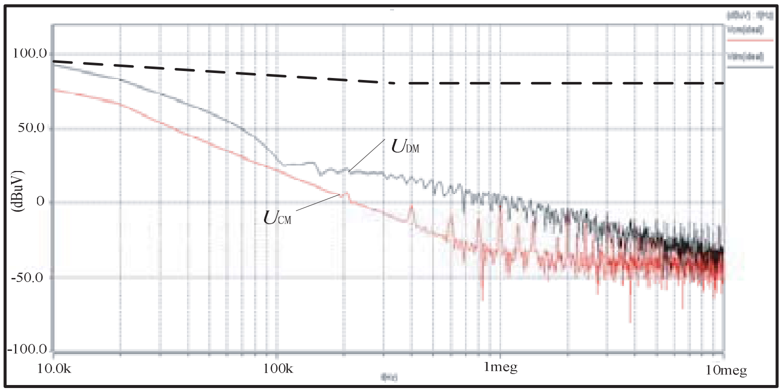
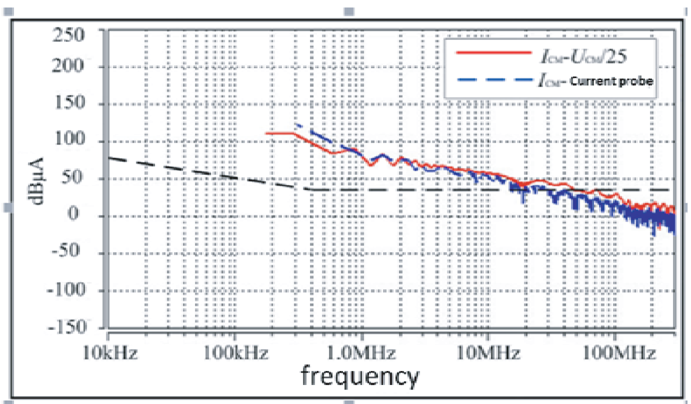


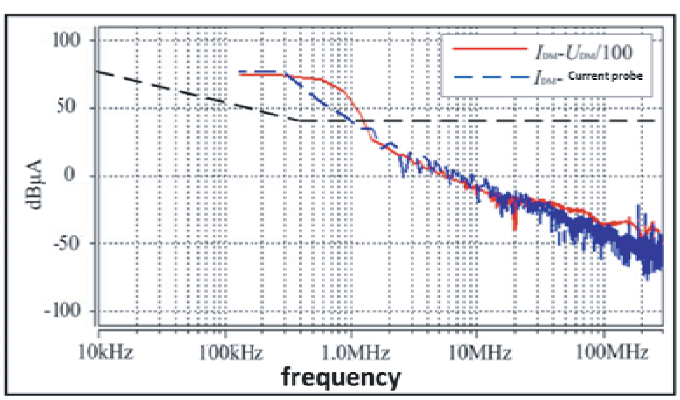
Figure 5. CM and DM spectra.

4. MODEL AND MEASUREMENT METHOD VERIFICATION

The common and differential mode interference spectra of the PSFB are illustrated in Figure 5 (the dotted line in the figure represents the CE102 limit). From the simulation results, it is found that the common mode and differential mode interference spectra in the 200 kHz $\sim$ 10 MHz band are below



(a)



(b)

Figure 6. Measurement of conduction EMI in PSFB. (a) $I_{\rm CM}$ spectrum comparison chart, (b) $I_{\rm DM}$ spectrum comparison chart.

0 dBμV, and the conduction interference has less effect.

Figures 6(a) and 6(b) show the DM and CM current spectra measured by the two measurements.

It can be seen from the comparison results of the two methods that the current interference spectrum obtained by the time domain digital measurement method has a high matching degree with the current probe measurement result.

5. CONCLUSION

As an electrical utility, an electrical utility demands that every piece of power equipment installed on the system meets the exact specifications. Thus, its compatibility with the internal and external propagations and low-frequency and high frequency disturbances within electromagnetic environment must be ensured.

Many of the EMI analyses and optimization techniques mentioned in the literature only involve one aspect of the converter and propose some improved results. However, it is very difficult to meet EMC certification standards for the accuracy of models calculation mentioned above, which is worth studying.

In this paper, a high-frequency model of PSFB circuit is established based on the impedance characteristic analysis method. The correctness of the time domain signal of port noise of LISN in wide-band is verified. The proposed procedure has been experimentally validated in two case studies, both in terms of component model and complete model of PSFB circuit. The simulation process and test platform are strictly set according to the standard. Numerical simulations and experiments match well, which show the effectiveness and validity of the conclusions in this paper. It is expected that our work can be applied as a useful reference for EMI analysis and optimization techniques.

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